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| 14. ABSTRACT The purpose of this Phase I STTR was to design an augmented reality (AR) training system to improve tactical combat casualty care (TCCC) training. The Macrocognitive AR Trainer (MART) developed in this Phase I project will be used to test AR-based adaptive training components, to improve and refine TCCC training, and to develop a principled approach to designing AR training. During this Phase I, we met each of our objectives: generated solutions for matching AR content to a physical manikin in a way that the virtual content moves with the physical manikin; developed a MART prototype; created two TCCC training scenarios (tension pneumothorax and airway obstruction); and designed an evaluation plan to investigate the effects of AR on training. Major findings of this effort include the acceptable feasibility of our approach and technology, including a defined commercialization path. The operational MART prototype received positive early feedback from potential military and civilian customers. | | | | | |
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PRINCIPLED DESIGN OF AN AUGMENTED REALITY TRAINER FOR MEDICS: PHASE I FINAL REPORT

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1. INTRODUCTION

The overall goals of this research program are to improve tactical combat casualty care (TCCC) training and to develop a principled approach to designing augmented reality training for combat medics. As a first step, this Phase I STTR focused on determining the technical feasibility of developing an augmented reality (AR) combat medic training system that incorporates adaptive training principles. During this Phase I effort, Unveil, LLC sought to integrate AR with smart manikins to create learning experiences that are scenario-based and interactive. We developed scenarios that train and assess the macrocognitive skills of sensemaking (e.g., diagnosing patient conditions), problem detection, cue recognition, and treatment planning in dynamic environments. The objectives of this project were: 1) overcome the technological barriers to mapping AR images onto physical manikins; 2) develop prototype AR-based training; 3) create two training scenarios (tension pneumothorax and airway obstruction); and 4) design a pilot study that integrates instructional system design principles and macrocognitive measures. The resulting AR-based adaptive training platform will be the foundation for a series of studies that will inform an evidence-based set of principles to guide the design and use of AR-based training in Phase II and beyond.

2. OVERALL PROJECT SUMMARY

TCCC is a military training approach that focuses on treating the most common fatal (but treatable) battlefield injuries - massive hemorrhage, tension pneumothorax, and airway obstruction. TCCC is effective - since it was implemented, combat deaths from these injuries have declined (Holcomb, 2009; Gresham & Rodriguez, 2005-2006; Bottoms, 2006). Part of the Joint Trauma System (JTS; DoDI 6040.47 Joint Trauma System, 2016), current TCCC training focuses on the skills required to treat these types of injuries, but not the perceptual cues and mental models needed to quickly size up a situation and react appropriately. Furthermore, a retrospective chart review of patients who received pre-hospital cricothyroidotomy during combat operations in Iraq and Afghanistan between September 2007 and July 2009 revealed that only 68% of the procedures were successful, suggesting that there may be training gaps associated with assessing the effectiveness of some medical procedures in the field (Mabry & Frankfurt, 2012). Knowing how to do a procedure is only useful when coupled with the knowledge of when the procedure must be used, and how to monitor whether it has been effective. We believe that well-designed AR training can help fill these gaps in the TCCC training curriculum.

During the course of this Phase I STTR, Unveil advanced its existing training system prototype to better meet the needs of the combat medic community. Our product, the Macrocognitive Augmented Reality Trainer (MART), consists of an AR headset, worn by the student, a smart manikin, and an instructor tablet. For this project, we used the Microsoft HoloLens AR headset, the Tactical Operations Medical Manikin (TOMManikin), and a tablet-based app for the instructor interface. The software developed during this project is hardware-agnostic.



Figure 1. MART platform ecosystem, including an AR headset, smart manikin, and instructor tablet app

The overarching goal of a Phase I STTR is to establish the technical merit, feasibility, and commercial potential of a proposed idea. To establish feasibility, the specific objectives of the current STTR project were to:

1. Overcome technological barriers to mapping AR images onto physical manikins
2. Develop prototype AR-based training
3. Create training and evaluation scenarios around two common battlefield conditions:
 - a. Tension pneumothorax
 - b. Airway obstruction
4. Design a pilot study to test the AR training technology

We articulated 7 tasks required to achieve these objectives. Below, we list the major activities and accomplishments associated with each of these tasks. Then we provide additional details about methods, approach, and outcomes for each task within the context of the project objectives.

Project Tasks

Task 1: Kickoff and IRB submission

We held an internal kickoff to orient the entire team to the project goals, objectives, and tasks. Unveil also traveled to the Office of Naval Research to attend a kickoff meeting with the contracting officer's representative (COR), Dr. Ray Perez and other ONR personnel. The meeting provided insight into ONR priorities and informed detailed project planning.

Task 2: Scenario development

We interviewed four emergency medicine subject matter experts (SMEs) about tension pneumothorax and airway obstruction cases they had experienced. We used exemplars from these interviews to draft two training scenarios (one for tension pneumothorax, one for airway obstruction). We sent the draft scenarios to the SMEs to review and respond to, then revised based on their feedback. Scenarios are discussed in more detail in the description of Objective 3 below.

Accomplishments associated with Task 2 were:

- One tension pneumothorax training scenario
- One airway obstruction training scenario

Task 3: Expert model development

When the SMEs reviewed the draft training scenarios, they also responded to a series of cognitive probes designed to help them articulate how they would assess, treat, and plan for the patient in each scenario.

We integrated responses from SMEs to create an expert model for each of the two training scenarios. Team member Oliver Smith, Paramedic Jumper (PJ) and Combat Rescue Officer (CRO), refined the integrated expert models. The expert models are discussed in more detail in the description of Objective 3 below.

Accomplishments associated with Task 3 were:

- Expert model for tension pneumothorax training scenario
- Expert model for airway obstruction training scenario

Task 4: Prototype development

There were three main efforts associated with the MART prototype development that we pursued simultaneously. One effort was to develop the virtual patient and virtual props to match the training scenarios. A second effort was to investigate new technologies to improve virtual patient registration (i.e., “anchoring” the virtual patient to a physical manikin, so they move together). The third effort was to develop a plan for incorporating adaptive training components into MART. Each of these development activities are discussed in more detail in the descriptions for Objective 1 and Objective 2 below.

Accomplishments associated with Task 4 were:

- Virtual patient registration proposed solutions
- Virtual patient with virtual props to match training scenarios
- Description of adaptive training components

Task 5: Curricula integration

Integration into training curricula is critical for commercialization of the proposed training technology. For Task 5, we analyzed existing TCCC training, along with emergency medicine physician training (specifically at Ohio State University Medical Center) to identify strategies for integrating MART. We reviewed the Accreditation Council for Graduate Medical Education (ACGME) program accreditation requirements and met with training leaders and supervisors. We also observed simulation-based training (advanced airway management) at the Ohio State University Medical Center to see how standard training sessions operate. Additional details about the activities related to curricula integration are discussed in the description of Objective 2 below.

The accomplishment associated with Task 5 was:

- Curricula integration plan

Task 6: Study design

For Task 6, we first reviewed literature related to evaluating and measuring macrocognitive skills. We also reviewed literature related to instructional systems design and evaluating training programs. The team articulated hypotheses about how about how AR could be used to support adaptive training and identified strategies for testing the strengths and limitations of individual adaptive training components. Additional details are discussed in the description of Objective 4 below.

Accomplishments associated with this task were:

- Study plan
- Evaluation measures

Project Objectives

The seven tasks articulated in the previous section supported each of the four project objectives. In this section, we describe our research activities, results and outcomes, and discuss each objective in terms of the overall research goal of creating evidence-based principles about the design and use of AR training and applying those principles to improve TCCC training.

Objective 1: Mapping the Virtual Patient to a Physical Manikin

Our first objective was to develop a technological approach to integrating the virtual patient with a physical manikin. Physical manikins are well-suited to support practice at applying interventions (i.e., tourniquet, needle decompression, cricothyroidotomy, etc.), but have limited ability to depict the changing condition of a patient (i.e., changes in skin tone, mental status, injury progression). For this project, we partnered with Innovative Tactical Training Solutions (ITTS), integrating the virtual patient with ITTS's TOMManikin to fully capitalize on the strengths of AR to present perceptual cues and provide a more seamless training experience.

The challenge was to develop a registration process that would anchor the virtual patient to a physical object. This allows the virtual patient to line up with the physical manikin, and to correlate movements in the physical manikin with movements in the virtual patient (i.e., if the manikin's arm moves, so does the virtual patient's arm). We anticipate that finding the right technology solution to anchor the virtual patient to a physical manikin will provide a more realistic training experience and improve learner interactions with the system. The Unveil team devoted part of the Phase I effort to researching and testing a number of potential solutions.

Methods. We began by identifying technologies that could be adapted to work in simulation-based training environments, that could be used in an easy and naturalistic manner by the end user, that would be compatible with our simulation platform and graphics engine, and that would have the potential to work across a variety of mixed reality headsets and operating systems.

We tested different technologies to determine whether we could show a real-time synchronization between the location and orientation of physical objects to virtual counterparts in a mixed reality view. First, we developed hardware firmware and software application programming interfaces (APIs) for integrating potential registration solutions into the mixed reality testing platform. Then, we could test the potential registration solutions in tracking manikin movements within the mixed reality testing platform on a desktop computer.

Outcomes. We identified three promising technologies that fit the required system parameters: 1) real-time skeletal tracking using 3D depth sensors, 2) inertial measurement units (IMUs) added to the physical manikin, and 3) visual tracking using markers applied to the manikin. Eventual solutions will incorporate combinations of these technologies, depending on the context of use. Each has important strengths described in more detail below.

Skeleton tracking is an application of machine vision technologies that can be used to understand and track human gestures. Skeleton and hand tracking are currently used in support of Natural User Interfaces (NUIs). Microsoft Kinect is an example of a commercial product that uses skeleton tracking. During the Phase I, we tested whether this technology would be able to track a manikin. We tested the Microsoft Kinect (Figure 2) and the Orbbec system (Figure 3). Microsoft has stopped supporting the Kinect system, but Orbbec is currently available and has the added benefit of working across a variety of operating systems. Our Phase I research and prototyping efforts demonstrated that the humanoid attributes of a medical training manikin were trackable with the skeleton tracking technology, making it a viable candidate in support of dynamic patient registration. However, the 3D depth sensors required for skeleton tracking limit the application to controlled environments, such as dedicated simulation centers. For videos of our technological studies of skeleton tracking systems, please visit the following links: Microsoft Kinect Tech Study: <https://youtu.be/2n2ukNkLKDU>, Orbbec Tech Study: <https://youtu.be/NMK4LBsCv3Q>.

Inertial measurement units (IMUs) are electronic devices that measure and report an object's force, angular rate, and in some cases, surrounding magnetic field. This hardware uses a combination of gyroscopes, accelerometers, and sometimes magnetometers. IMUs are placed directly on the object being tracked. During Phase I, we tested whether multiple IMUs could be customized to be chained and attached to the manikin to track the manikin's movements and mirror the movements in the virtual

patient. Our testing and prototyping activities demonstrated that our customized IMUs can provide a robust solution to tracking a manikin's limb movements (Figure 4). One potential drawback of this approach is that custom hardware development and integration will require more time and resources to bring to market. For a video demonstration of the technology study of IMUs, see IMU Tech Study: <https://youtu.be/VFWAsvAZA40>.

Microsoft Kinect



Figure 2. Microsoft Kinect skeletal tracking tech study

Tech study link:
<https://youtu.be/2n2ukNkLKDU>

Orbbec

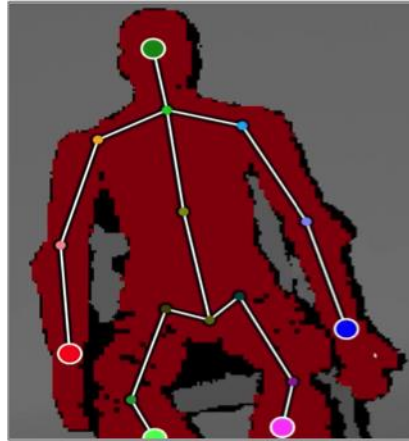


Figure 3. Orbbec skeletal tracking tech study

Tech study link:
<https://youtu.be/NMK4LBsCv3Q>

Chained IMUs

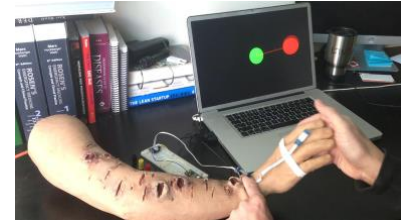


Figure 4. Chained IMUs tech study

Tech study link:
<https://youtu.be/VFWAsvAZA40>

Marker-based tracking uses visual patterns or images to allow a computer vision system to detect and track an object in a field of view. For example, one of Unveil's other products, Chiron™, utilizes a paper skull with distinctive visual patterns to facilitate robust object detection and tracking from all viewable angles.

When the object is detected within the field of view of an AR application, a 3D render of a patient's head appears in the AR view showing signs and symptoms of a condition (e.g., head trauma; see Figures 5 and 6). Marker-based tracking is currently supported in all the major AR platforms as a means to add virtual content to physical objects, lowering the technical barrier for implementing AR content. However, a purely marker-based approach requires changing the manikin's outward appearance or introducing additional physical props. The technology does not work if the marker is not in the field of view of the computer vision system.



Figure 5. Chiron paper skull with fiducial markers

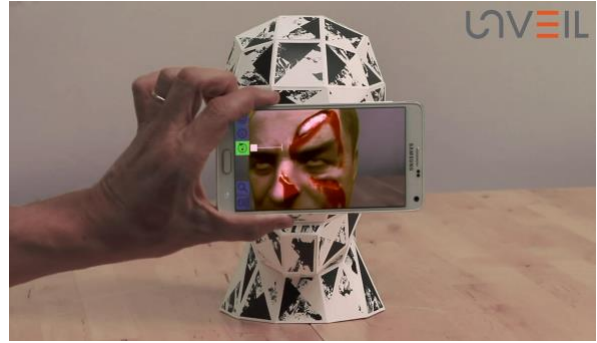


Figure 6. Chiron's AR content showing a head injury

Conclusions. We envision using a combination of technologies based on the intended use case for the MART system. For the Phase II, we envision a portable version that can be quickly set up in any classroom, simulation facility, or even field setting. IMUs embedded into the manikin combined with discreet visual markers are the most promising approach for portable use. For medical training simulation centers where students come to a dedicated space to interact with the system, we would likely add environmental 3D depth sensors to our solution to capture more data about student performance. We anticipate that the tight coupling between virtual content and physical props will be a requirement for the type of skills training that combat medics need. Virtual patient registration is an important foundational step for testing the effectiveness of our proposed training components.

Objective 2: Develop Prototype AR Training

While Objective 1 was focused on the technological advancement of MART, Objective 2 was focused on creating its training content and approach. There were three main activities associated with Objective 2: creating virtual content, articulating the training strategy, and developing a curricula integration plan. We created a virtual patient to correspond with our training scenarios along with other virtual support items such as diagnostic tools and medical interventions (for a video demonstrating the MART Combat Medic version of the system, please visit <https://youtu.be/HjVxyiKczME>). We also articulated a strategy for incorporating adaptive training components into MART. With AR technology, learners are able to interact with the physical environment and virtual content seamlessly. This functionality affords the ability to inject hints and guidance to learners as they work through training scenarios. Learners can see or hear virtual hints and guidance, immediately practice physical interventions, and receive instructor feedback about their actions. Finally, we articulated a curricula integration plan for incorporating MART into resident physician training as an important step towards commercializing our approach. The methods and outcomes associated with each of these main activities are described in turn.

Virtual Patient and Software Development

Methods. We created the virtual patient and virtual props to accompany the training scenarios using an iterative design and development process. We worked closely with our combat medicine SME (Oliver Smith, PJ, CRO); he reviewed multiple rounds of design and offered feedback regarding the appropriateness of virtual patient and objects throughout the process. We bundled and deployed the virtual assets (i.e., virtual patients, props) to the HoloLens mixed reality platform at various stages of development so we could confirm their medical accuracy and verify that the virtual assets maintained a reasonable level of graphics performance.

We expanded the existing programmatic models of the software (HoloLens mixed reality software, tablet software) to support virtual patients with multi-system TCCC injuries. We also developed airway TCCC scenarios to match the airway training scenario and other closely related injuries. Additionally, we evolved the data models underlying the patient conditions. The data models were expanded to support multi-system medical patients and to support the virtual depiction of properly and improperly applied medical interventions to make the training more realistic.

Outcomes. We created virtual content that matches the parameters specified in the training scenarios (virtual patients and relevant virtual treatment interventions; Figures 7 and 8). The virtual patients show a progression of injury state from point of injury to death, broken into discrete stages. The pulse oximeter is a virtual prop that appears on the patient's finger to give blood-oxygen saturation levels throughout the progression of stages. The virtual interventions can be added by the student wearing the HoloLens by issuing a verbal command ("Show intervention") or by the instructor by tapping on the intervention from the tablet's app.

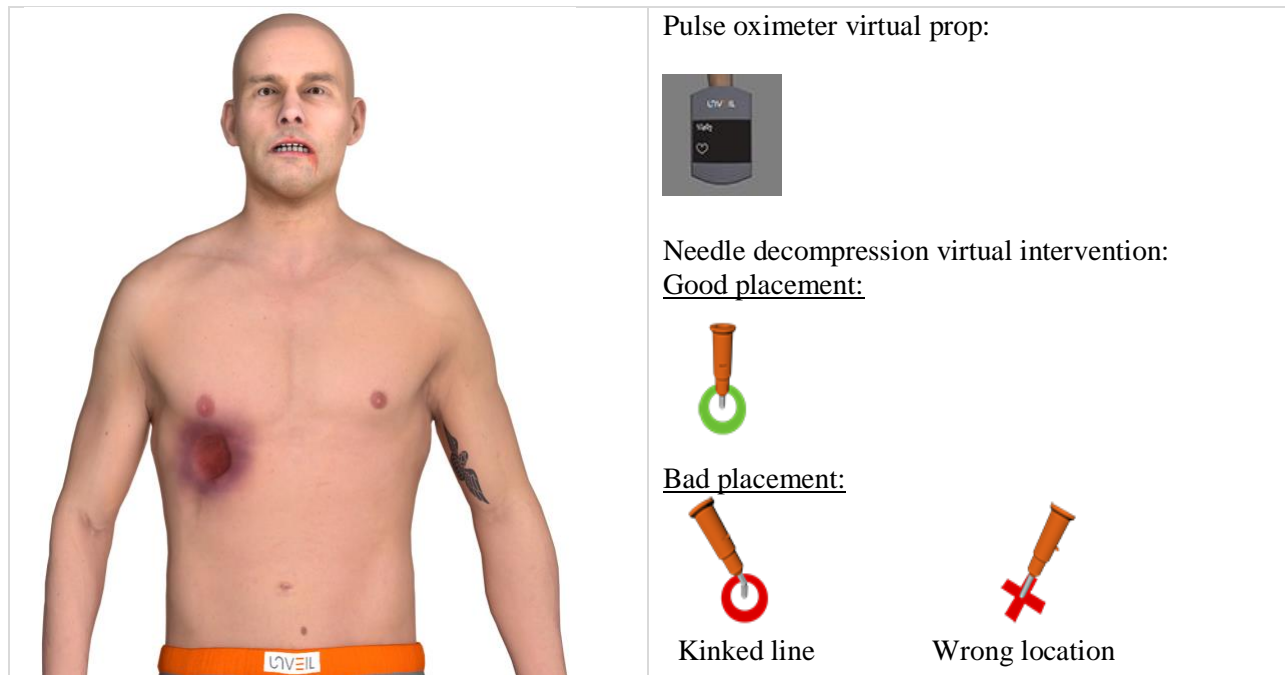


Figure 7. Tension pneumothorax virtual patient with virtual assessment and treatment interventions

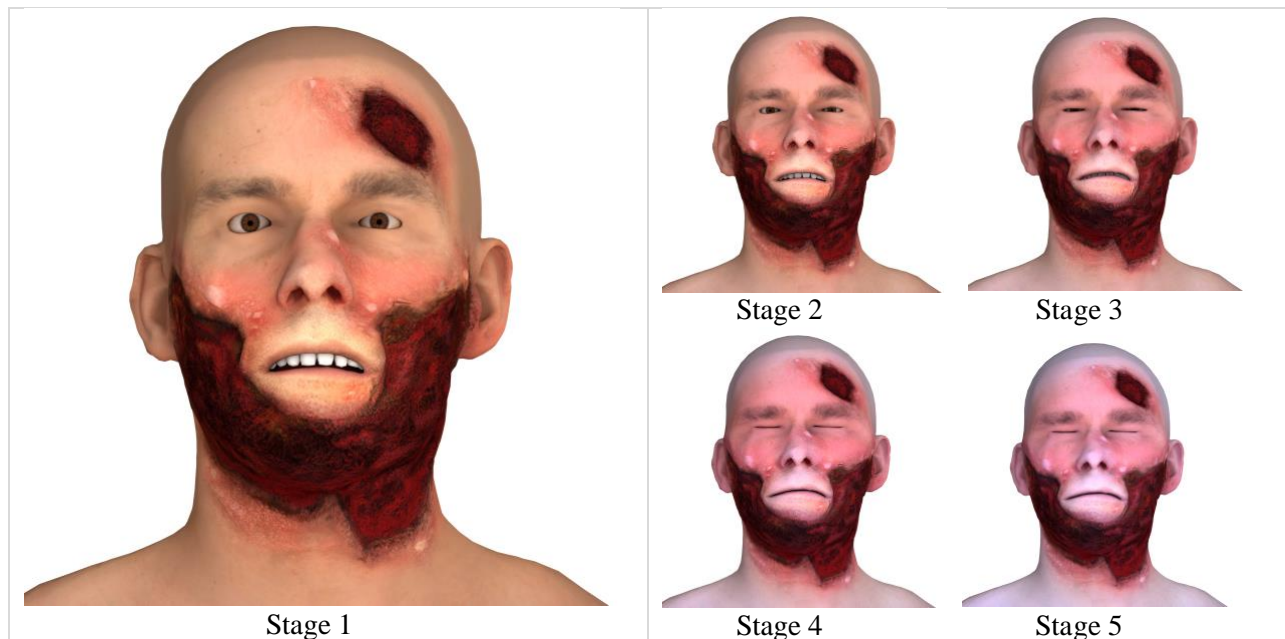


Figure 8. The five stages of the airway obstruction training scenario showing increased swelling and eventual loss of airway.

Adaptive Training Structure and Design

Approach. Our approach to creating MART's adaptive training components is based on findings from the Naturalistic Decision Making (NDM) and cognitive expertise literatures. Ericsson, Charness, Hoffman, and Feltovich (2006) articulated the importance of learners being actively involved in experiencing and interpreting cues in the environment. MART's adaptive training components are designed to leverage the abilities of AR to strengthen the first-hand experiences of learners to actively engage them in what they are learning.

Research shows that the development of expertise is not a passive process. There are several elements that help learners develop expert knowledge. For example, exposure to an expert model has been shown to accelerate skill acquisition (Hoffman et al., 2014; Klein & Borders, 2016; Pliske, McCloskey, & Klein, 2001). Another element that has been demonstrated to differentiate experts from non-experts is reflection (Ericsson, 2004; Ericsson et al., 2006). People who become experts reflect on their experiences and speculate how situations may have gone differently. They develop their own lessons learned that they can apply to novel situations. Research also shows that skill acquisition is better in learners who are motivated to learn, engaging in "deliberate practice" (Ericsson, Krampe, & Tesch-Romer, 1993; Ericsson, 2006; Ericsson et al., 2006). Each of these constructs (i.e., expert model, reflection, deliberate practice) is incorporated into our proposed adaptive training components.

The process of learning new content and skills can be helped by the structure of the instruction itself. Research has shown the critical importance of feedback in skill acquisition (Ericsson, Krampe, & Tesch-Romer, 1993). With a well-designed AR system, we can incorporate feedback to the learners when it is most beneficial, both in real time and as summary feedback, or "knowledge of results" (Xeroulis et al., 2007; Wulf & Shea, 2004). The structure of training and how much support is offered should vary with learner skill level. For example, a novice might benefit from real-time guidance and hints that an advanced learner would find tedious. We will incorporate scaffolding principles (Wilson & Devereux, 2014) into MART's adaptive training design. Scaffolding is a technique to move learners progressively toward stronger understanding and greater independence in the learning process, teaching learners how to direct their own attention and actions.

Outcomes. We articulated a structure for the adaptive training component of our system. We envision three classes of learner: early novice (Level 1), intermediate learner (Level 2), and advanced learner (Level 3). The system will behave differently depending on the learner's level, using different combinations of training components. We articulated training components for both the student and the instructor.

Learner-Facing Adaptive Training Components. We identified 5 learner-facing adaptive training components to be developed and evaluated in Phase II. The first is the use of *attention-directing hints*. In the simplest form, this will appear as a voice avatar representing a more experienced medic (or physician) encouraging the learner to notice or look for something specific (i.e., *Is he bleeding anywhere else? Have you looked inside his mouth to see if the airway is swelling?*). This approach supports the learner to obtaining first-hand experiences in the context of challenging cases. Aimed at novice and intermediate learners, this approach provides important scaffolding, and also retains important realism by using a voice avatar of a mentor/colleague.

Another type of attention-directing hint we will explore is the use of visual pointers (Figure 9). A visual cue might point to an appropriate intervention. As compared to a voice avatar directing the learner to look for signs of airway swelling or describing appropriate needle placement, the pointer on the anatomy reduces ambiguity for the learner, making it most appropriate for novices.

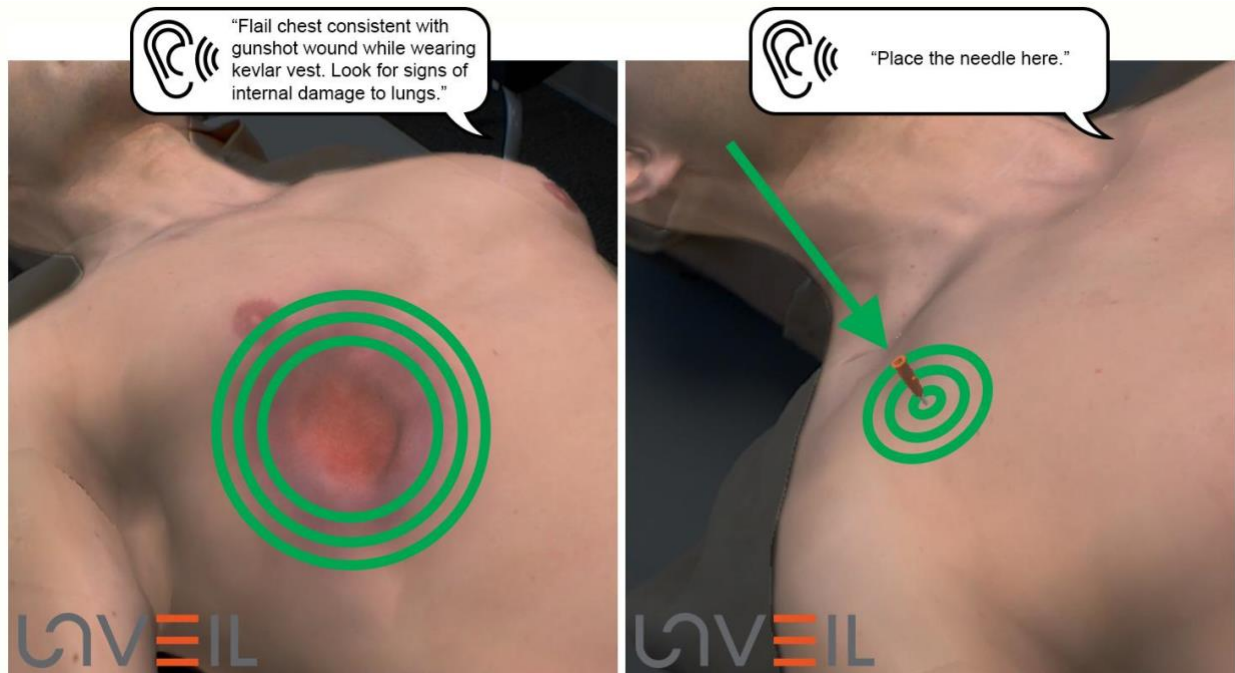


Figure 9. Visual pointer showing where an important cue is located (left), and a visual cue guiding the learner to an appropriate intervention (right)

A second adaptive training component is *real-time auditory correction*, intended to aid the learner in conducting a thorough assessment using a relevant algorithm. This training component incorporates real-time feedback into the training scenario. For example, many medical schools use the Airway, Breathing, Circulation, Disability, Expose the patient, Foley and rectal (ABCDE) algorithm, whereas combat medics use the Massive hemorrhage, Airway, Respirations, Cardiac, Head injury/Hypothermia (MARCH) algorithm. When the learner deviates from the appropriate algorithm (i.e., delays assessing airway because of distracting head injury), an auditory correction will remind the learner to walk through the assessment in the correct order. This intervention is aimed at novice and intermediate learners.

A third adaptive training component is the use of *3D animation to show underlying dynamic anatomy*. Although a learner may have read descriptions of what happens inside the chest cavity when a tension pneumothorax develops, seeing an animation juxtaposed with the physical appearance of the patient may have added training benefit. By situating instructional animations of injury processes in realistic scenarios, our training will aid learners in building more robust mental models and improve their ability to visualize the implications of the injury, anticipate future states, and identify appropriate treatment options. This intervention is aimed at novice and intermediate learners.

A fourth adaptive training component is to *manipulate time* using AR. It will be possible to show how the patient condition degrades over time without medical intervention by compressing time scales. The learner may see the virtual patient immediately following an injury, and then at whatever time intervals are required to demonstrate the progression of an injury. For a tension pneumothorax, this might jump forward several hours, while an airway injury might unfold in a matter of minutes. The learner can also jump back and forth in time to compare cue representation. For example, the learner might first notice jugular vein distention (JVD) at Stage 4 of a scenario, but wonder if s/he could have noticed it earlier. The learner could then flip back and forth between Stage 2, Stage 3, and Stage 4 to see how the JVD initially appeared, and how far it progressed. This component supports feedback and first-hand experiences.

The *performance summary* is the fifth adaptive training component, made up of three parts: expert model, replay, and performance score. For intermediate and advanced learners, the performance summary will

highlight where student performance deviated from the expert model based on gaze tracking data and instructor input. It will be possible to revisit portions of the scenario from the perspective of the learner. This will allow the learner to review cues that were missed or misinterpreted. Finally, learners will receive a performance score in which points are awarded for appropriate actions, and subtracted for hints used and errors. The integration of these features into a performance summary will support summary feedback, reflection, and deliberate practice.

Instructor-Facing Adaptive Training Components. To support the trainer in using the AR-based adaptive training system we have four instructor-facing components. To track perception and recognition, the *gaze tracking* feature allows the trainer to see where the learner is looking. Furthermore, gaze tracking data can be compared to the expert model to highlight gaps and errors. If the learner has not yet looked at the pulse oximeter, for example, the instructor-facing software will highlight this omission (see Figure 10).

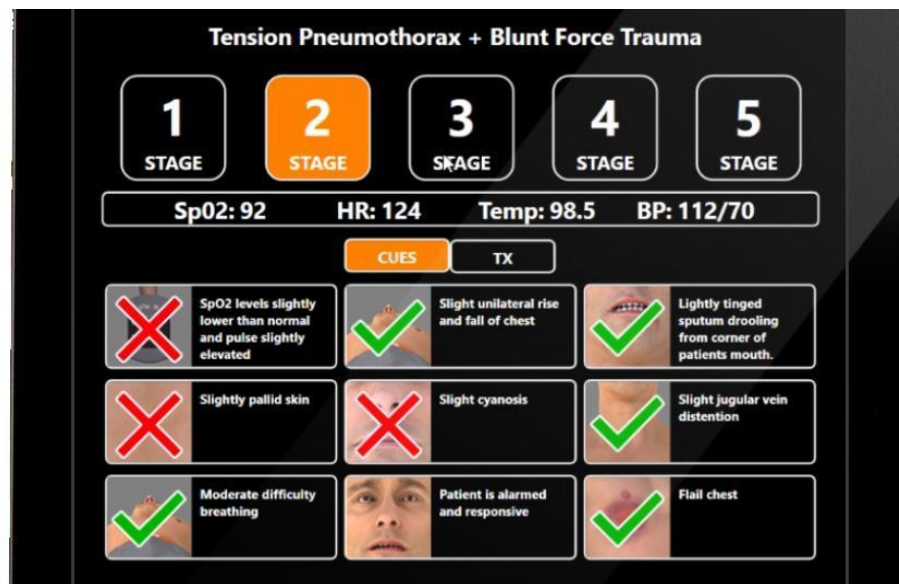


Figure 10. Instructor tablet view showing gaze tracking results. Green checks indicate cues that the student has looked at, and red Xs are cues that have been missed.

To aid in applying appropriate scaffolding, the instructor-facing app will *highlight common errors*, as well as specific errors made by the learner, and suggest scaffolding techniques at relevant points in the scenario. For example, the software will suggest a specific hint if the learner seems to have missed an important cue.

To support the trainer in evaluating student performance, the instructor interface allows the trainer to *mark any part of the scenario* for later discussion and replay, such as notes about good or poor technique.

To support the trainer in providing constructive feedback, the *performance summary* page can be used to highlight differences between student performance and the expert model, access expert rationale for specific actions, and replay specific points in the scenario.

Curricula Integration Plan

The goal of this project is to improve TCCC training. However, to take advantage of partnerships already in place, we plan to test curricula integration efforts with the Ohio State University Medical Center. The Accreditation Council for Graduate Medical Education (ACGME) accredits all graduate medical education in the United States, including residency physician training programs for all specialties. In 2014, the ACGME mandated the Next Accreditation System (NAS), which provided increased flexibility in meeting ACGME competencies, in part to allow simulation-based medical education. In many residency programs, there is a procedural skills curriculum with specific procedures required for each

specialty. A common procedural skill trained in all programs is airway management, in large part to avoid harm from learning a procedure on real patients. For example, the initial success rate for first-time tracheal intubation is between 35 and 65% (Nouruzi-Sedeh, Schumann, & Groeben, 2009), as compared to over 90% for experienced physicians. With a failed tracheal intubation, there is the possibility of perforation or laceration of the surrounding areas, as well as infection.

At Ohio State University, all resident physicians in emergency care, trauma care, and anesthesiology participate in simulation-based training to meet ACGME requirements for airway management, which includes a tension pneumothorax patient. The training occurs in the Prior Hall Simulation Center in the procedural skills room with a part-task training manikin that includes an open airway, tongue, and inflatable balloons that represent the lungs and the stomach. Extensive airway management equipment is available that interfaces with the manikin. Cases are face valid. At the completion of the case, the resident completes a self-assessment and an educator completes an assessment. If the resident passes, then the video serves as proof of competency for ACGME accreditation. If the resident fails, remediation occurs real-time and a retake test is scheduled. In addition, extensive simulation capstone scenarios are run with a full body manikin that includes airway management elements in addition to other elements. In this situation, vital signs data and breathing sounds are included as part of the simulation, and the session is video-recorded.

Representatives from the OSU residency physician program expressed an interest in training with a virtual patient independent of a physical manikin. The vision is that rather than integrating with a manikin, the virtual patient would appear on the hospital bed where a manikin is typically situated. An instructor will use a tablet to view real-time gaze tracking and other relevant data for facilitating the session. In order to accommodate learning in small groups, they have asked us to explore strategies for displaying the augmented reality view simultaneously on a large monitor in the simulation room.

Conclusions. We were able to create virtual assets (patients, props) and upload them to the HoloLens mixed reality platform so they could run with high quality graphical resolution. We updated the underlying data models to reflect the training scenario parameters. We are working on streamlining the process of creating new virtual content to match new scenarios and injury types. We began exploring a new underlying patient architecture that would allow us to decouple specific parameters (e.g., heart rate, skin tones, blood pressure, etc.) to provide near infinite flexibility in how the patient's vital signs, cues, and symptoms are combined to depict a medical condition. Instead of having a “tension pneumothorax” scenario and a “burned airway” scenario, we could mix and max different injuries and conditions to create new scenarios much more quickly. We believe this new approach can better support our envisioned adaptive training framework as well as (down the road) integrate with bio-physics engines, such as BioGears, to allow for dynamic, medically accurate simulations.

MART will be an adaptive training system in that it will behave differently based on the skill level of the learner. The presentation of the first four learner-facing adaptive training components (attention-directing hints, real-time correction, animation, and time manipulation) will be dependent on the mode selected. For Level 1 learners, MART will operate in tutorial mode, in which the learner is guided through the scenarios, and relevant hints, corrections, and animations will automatically appear at relevant times in the scenario. For Level 2 learners, MART will enter a high challenge/high support mode (Wilson & Devereux, 2014), in which hints, corrections, and animations are available to learners if they ask, if the instructor thinks they need additional support, or if the system determines that they are going down an incorrect path. At this level, learners are self-directed through the scenario, but there is scaffolding in place to ensure they do not fail. For Level 3 learners, MART enters a high challenge/low support mode (Wilson & Devereux, 2014), in which hints are not available and the learner is able to fail. Discussions with emergency medicine SMEs with training experience emphasized the importance of allowing students to fail in emergency medicine training scenarios.

We have a plan for implementing specific components of the MART system into an existing resident

physician training program. As many resident physician training programs are already employing simulation-based training using manikins, it is expected that our university partner, Ohio State University, can serve as a 'best practice' model for implementation of AR for airway management and tension pneumothorax training and have lessons learned via traditional dissemination pathways to other academic medical centers. We have three physicians on our team for the Phase II who will assist in creating the practice model at OSU. Dr. David Bahner will aid dissemination efforts to emergency and trauma care medicine at OSU, Dr. Michael Barrie will facilitate the exploration of an expansion of the training module for fourth year medical students in emergency medicine, and Dr. Susan Moffatt-Bruce will serve as the interested customer for purchasing the technology and associated training. We will develop 'Best practice' principles for the use of AR with simulation-based training for medical students at the graduate and undergraduate level, and we will disseminate these principles and lessons learned via professional conferences in medical education.

After integrating MART into the curricula at Ohio State University, we will be better positioned to integrate MART into the TCCC training curricula. We plan to leverage our partnership with Innovative Tactical Training Solutions (ITTS), who manufactures the TOMMankin. ITTS has existing agreements with many military training clients, and has agreed to sell the pre-cursor to MART, the Virtual Patient Immersive Trainer (VPIT). Please see the Commercial Feasibility section in the conclusion of this report for more details.

Objective 3: Create Training and Evaluation Scenarios

Objective 3 was to create two realistic, challenging training scenarios -- one for tension pneumothorax and one for airway obstruction. We also created expert models to correspond to the two training scenarios. Another piece of Objective 3 was to create evaluation scenarios; we developed a framework for creating evaluation scenarios using the garden path scenario method.

Methods. To create realistic, engaging scenarios, we interviewed one pararescue jumper (PJ) and three emergency department physicians. We used Cognitive Task Analysis (CTA) interview techniques (Militello & Hutton, 1998; Hoffman & Militello, 2008) to elicit a case base of real-life incidents involving tension pneumothorax and airway obstruction injuries. These are two of the most common treatable, yet potentially fatal injuries experienced on the battlefield (Holcomb et al., 2007; Kelly et al., 2008; Gerhardt, Mabry, De Lorenzo, & Butler, 2012). CTA techniques are used to articulate the cognitive aspects of a particular job, especially the tacit aspects of expertise. CTA methods include in-depth, incident-based interviews and observations of expert performance in naturalistic or simulated settings.

For this project, we employed a specific CTA method called the Critical Decision Method (CDM; Klein, Calderwood, & MacGregor, 1989; Crandall, Klein, & Hoffman, 2006). During CDM interviews, interviewers guide participants through recalling an incident in which their skills were challenged. Through an iterative process, the interviewee deepens on the incident in terms of timeline, critical points during the incident, goals, optional courses of action, tradeoffs, cue utilization, contextual elements, and situation assessment factors associated with specific decisions. At the end of the interview, we asked the interviewee a series of hypothetical questions, including where a less-experienced person might have erred, and to explore the implications of certain cues and events. During these discussions, we gathered stories of patients who suffered from tension pneumothorax and/or airway obstruction injuries, along with elements that make treating these injuries difficult.

Outcomes. We used the CTA data to create two training scenarios (one for tension pneumothorax, one for airway obstruction). All four subject matter experts reviewed draft scenarios for realism, and described how they would respond at each decision point. These responses were used to refine the scenarios and build an expert model for each. Each scenario is described in terms of point of injury context and key signs and symptoms at set time points during treatment.

Training Scenarios

Scenario 1: Tension Pneumothorax. An explosive ordnance disposal (EOD) soldier was attempting to neutralize a small improvised explosive device (IED). The IED detonated during the deactivation attempt, causing a blast lung injury, temporary loss of consciousness, blunt force trauma to the rib cage, and burns to the patient's hands. The patient was thrown approximately 2 meters away from the blast site, and landed on pavement. This is an active combat situation, so a key concern is security. Patient is a male, 20-23 years old, approximately 180 lbs.

- Time 1: 30-60 seconds after point of injury (POI): At this point, the learner is able to do a quick assessment of the patient, but needs to stay alert to changing combat conditions. The patient does not show signs of massive hemorrhage, but there is some blood in his mouth. The patient has close to full respirations, but his inhalation volume is decreased. He has a fast rate of breathing and is showing some signs of breathing difficulty. The patient is alert, but is in pain and has superficial and partial thickness burns to his hands. Assessment is interrupted by active fire.
- Time 2: 15 minutes after POI: The area is now secure, so the learner is able to continue assessing the patient. The learner is able to determine that there are broken teeth in the patient's mouth, and it looks like the patient bit his cheek and tongue (explaining the blood in the mouth seen at Time 1). The patient has bruises on his right rib cage, and there is a slight paradoxical motion in the rise and fall of his chest. The patient is having more difficulty and increased effort of breathing. The patient is alert and talking in short sentences. The patient is now able to be moved to a more secure area.
- Time 3: 45-60 minutes after POI: The patient is now in a secure and protected area, and the learner is able to re-assess. Since the last assessment, the patient is breathing more rapidly and is now wheezing. He is becoming hypoxic and cyanotic. The paradoxical motion in his chest is more pronounced, and now there is an obvious flail chest segment. The bruises to his torso are larger and have changed color. The learner is able to see unilateral rise and fall of his chest. The patient is confused and his skin is pale.
- Time 4: 3 hours after POI: The patient has not yet reached a definitive care facility, but he is sheltered in a secure location. Upon reassessment, the learner notices that the patient is coughing excessively with productive red sputum. The patient has decreased breath sounds and there is blood coming out of his mouth. The patient is showing unilateral rise and fall of the chest, and his torso bruising has worsened. The patient shows jugular vein distention and tracheal deviation. His skin is pale and he is in and out of consciousness.

Scenario 2: Airway Obstruction. A rocket-propelled grenade (RPG) struck the driver side front door of an up-armored vehicle in a convoy. The driver (wearing a ballistic helmet, body armor, and gloves) was closest to the explosion and remained entrapped in the vehicle for approximately 90 seconds before his teammates were able to pull him from the burning wreckage. He received partial and full thickness burns around his neck, jaw, and upper cheeks. The body armor protected his chest from any direct burns or penetrating injury. The soldier's upper extremities were hit with shrapnel and debris. His gloves protected his hands, but there were ring burns around his wrist.

- Time 1: Immediately following POI: The learner is able to get to the patient shortly after he was removed from the burning vehicle. After getting the patient to a secure location, the learner assesses the patient. While there is blood on his uniform, it is from lacerations from debris; there is no massive hemorrhage. The patient has singed nostril hairs and the skin on his face and his lips is turning red, like he has been sunburned. There are also small pieces of shrapnel in his face. There are no major secretions in his mouth and his neck looks normal. His voice is hoarse and he is coughing. The patient has increased respirations, but his chest movement is normal. Patient is conscious but in pain and seems to be rambling. He is sweating and has light burns on his arms.
- Time 2: 5-10 minutes after POI: The patient has become lethargic and is in obvious respiratory distress, so you reassess. You notice that the tissue along his airway is beginning to swell, and the

patient is coughing up thick carbonaceous sputum with some yellow-green phlegm and blood. The skin around the patient's mouth is becoming a darker red, and blisters are forming across his cheeks and forehead. The patient's nostrils are becoming smaller, and there is general swelling around his face. There are more secretions in his mouth, and his pharynx is starting to close up.

- Time 3: 15 minutes after POI: Non-surgical attempts at managing the patient's airway have failed, and the patient's condition is worsening. The tissue in his nose and mouth is significantly swollen; his lips are triple in size. Larger blisters are starting to form on his face. The carbonaceous sputum and secretions in the mouth are very prominent. The learner hears stridor, wheezing, and wet lung sounds. The patient has an increased effort and rate of breathing. The patient is fatigued and has a muted cough.

Each of these scenarios describe the trajectory of the patients' injuries if appropriate medical interventions are not applied. The virtual patients were developed to reflect these scenarios.

Expert Models

We aggregated SME responses to the cognitive probes associated with each training scenario. We then coded responses and identified overlapping content areas. From these, we created expert models for each scenario, representing which cues the experts found most important at each time point, their differential diagnoses, planned actions, and expected prognosis for the patient. Team member Oliver Smith (PJ, CRO), reviewed and refined the integrated expert models to ensure that they represented a combat medic perspective. Full scenarios with the associated expert models are included in Appendix A.

Evaluation Scenarios

We tailored the Garden Path scenario approach to develop evaluation scenarios. Our original intent was to create two Garden Path scenarios to be used in a summative evaluation. However, we have modified our evaluation approach to include both formative and summative testing. To accommodate this shift, we created a framework that will allow us to quickly create Garden Path evaluation scenarios to incorporate into any type of evaluation (see Figure 11 below).

Garden Path scenarios (Patterson, Roth, & Woods, 2010) are useful for testing macrocognitive skills, such as sensemaking and problem detection. According to Patterson, Miller, Roth, and Woods (2010), *sensemaking* consists of collecting information and assessing how it fits potential explanations. *Problem detection* is noticing whether events are unfolding as expected or not, and whether a reframing of the situation is needed. Garden path scenarios are designed to assess how well and how quickly participants detect and synthesize information into correct hypotheses.

A garden path scenario begins with cues and signals pointing very clearly to a conceptualization of the situation (i.e., diagnosis) that appears accurate, but is ultimately incorrect. This original answer is known as the *false prime hypothesis*. When used in nuclear power, this false prime hypothesis could be the result of a reading from a faulty sensor that the operator does not realize is malfunctioning. The false prime is the result of bad information and leads the participant down the garden path.

As the garden path scenario unfolds, additional cues and signals are presented to the participant as either injects or discoverables. *Injects* are changes to the scenario that are unprompted by the participant (e.g., "The patient is now unconscious"). *Discoverables* are cues that are available upon request by the participant (e.g., the participant asks the experimenter, "What is the patient's heart rate?", and the experimenter gives the answer). Discoverables are akin to looking at instruments or test results, but require information-seeking behaviors on the part of the participant. These additional cues and signals are presented as subtle changes that indicate the underlying true explanation for what is occurring in the scenario. If the participant detects these changes and realizes that they do not fit into the initial false prime hypothesis, s/he should start to develop alternative hypotheses.

The main unit of measurement in a garden path scenario is time. We can measure how long it takes participants to discard the initial false prime hypothesis, how long it takes participants to generate

alternative hypotheses, and how long it takes them to arrive at the correct explanation for what is occurring in the scenario. De Keyser and Woods (1990) found that participants held on to the original hypothesis (that was ultimately incorrect) too long, failing to adjust their thinking during dynamic diagnosis in a complex setting. However, Hoffman and Fiore (2007) found that *experts* are less likely to be trapped in a garden path scenario and are better at recognizing the subtle perceptual cues that lead to the correct outcome. Novices tend to hold on to the initial hypothesis longer than experts, who are better able to perceive and interpret the subtle cues that indicate a different hypothesis would be more appropriate.

While garden path scenarios have been applied to military and nuclear power domains, they are less commonly used in healthcare research. We modified the traditional garden path approach in a few ways to better fit the domain of emergency/combat medicine. First, traditionally the false prime hypothesis is completely wrong. However, we recognize that trauma patients often have multiple injuries, some obvious and some obscure. The SMEs that we interviewed said that the most challenging cases are when there are distracting injuries that appear bad, but are masking a more insidious condition that will actually kill the patient if left unaddressed. Therefore our garden path scenarios will contain a false prime hypothesis that is related to the complete diagnosis, but is the wrong injury to focus on. For example, a partial limb amputation could be the false prime hiding an airway obstruction. The partial limb amputation is serious and might kill the patient, but the patient will definitely die if the airway is not secured. Because it is rare that a trauma patient would only have one or two injuries, our garden path scenarios will have a false prime hypothesis, several alternative hypotheses, and a complete diagnosis which will be a combination of the previously-generated hypotheses.

We will measure the time that it takes participants to rule out the false prime hypothesis as the primary explanation for what is wrong with the patient, instead of ruling the false prime out completely. We will also measure how long it takes participants to generate correct alternative hypotheses, and how long it takes them to arrive at the complete diagnosis. At the end of the scenario, we will reveal the correct diagnosis to support reflection and after-action review.

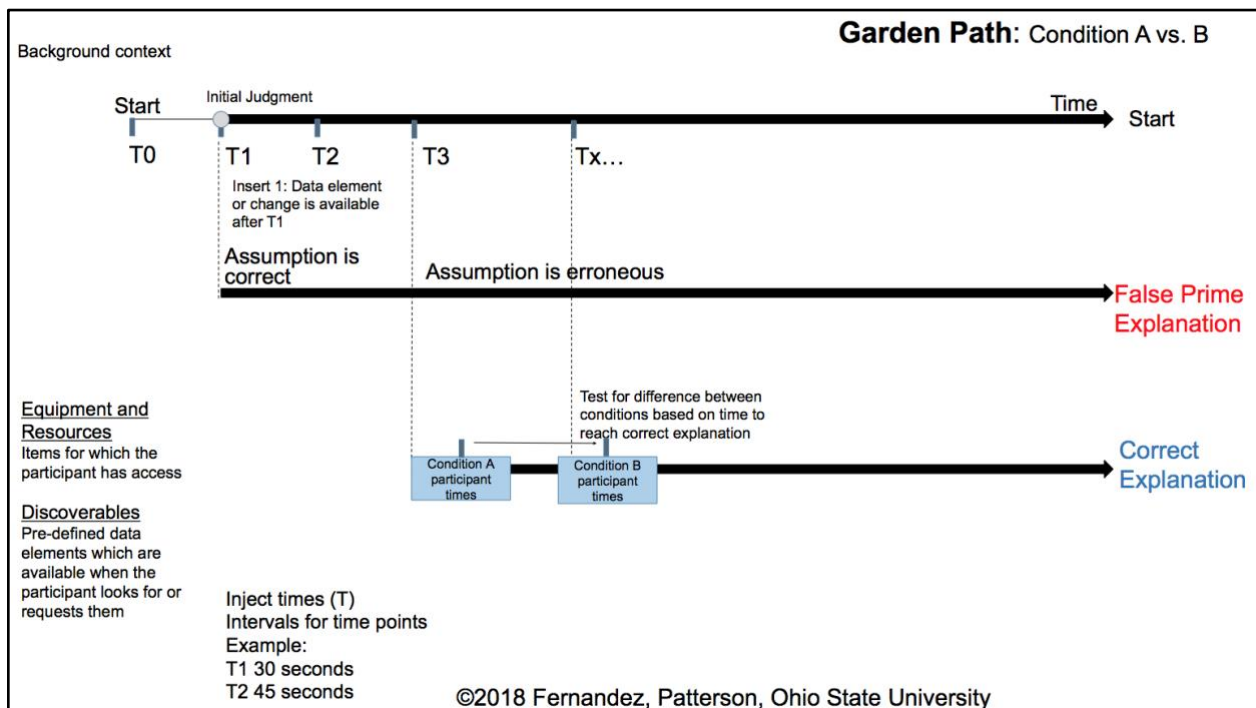


Figure 11. Visual depiction of a basic garden path scenario comparing performance with two conditions

Objective 4: Design an Evaluation to Test AR Training Technology

We developed a plan for a series of formative evaluations and user feedback sessions to test the effectiveness of specific components of MART to be carried out in Phase II. The formative evaluations will be a series of small-n controlled studies comparing an experimental group exposed to a specific MART adaptive training component, and a control group that is not. Focused user feedback sessions will include one-on-one sessions with combat medics, medical students, and instructors to explore issues of usability, perceived benefits and drawbacks, and strategies for integrating into existing training. Results from the formative studies and user feedback sessions will be directly incorporated into our software development cycle. We also planned for a summative evaluation study near the end of Phase II to test a complete MART training module. The team from our university partner (Ohio State University), led by Dr. Emily Patterson, worked on creating materials and articulating the method for the summative evaluation. The outcomes of this series of evaluations will be a set of AR training design principles that can be generalized to other AR training applications.

Method. We held several meetings with the project team to articulate important aspects of AR that we believe will impact training. We also reviewed literature related to the use of simulations, AR, and virtual reality (VR) in medical training. We articulated a series of research questions based on these AR elements, and chose the ones that seemed the most impactful. The goal of the evaluation effort is to determine *if* the MART system improves training along with *how* the system improves training.

Outcomes. The evaluation plan leverages both formative and summative evaluation activities to test components of the MART system, and inform evidence-based principles for designing augmented reality training. We will conduct a summative evaluation near the end of the Phase II in which we will compare the MART system to existing training. Table 1 summarizes the evaluation efforts in terms of the training design principle (left column), evaluation question (middle column), and performance measures (right column). Details for the formative and summative evaluations are provided below the table.

Table 1. Phase II evaluation plan

| AR Training Design Principle | Guiding Question | Measures |
|---|--|---|
| Formative Studies | | |
| 1. Embed AR-generated realistic cues , including multi-dimensional, multi-sensed, dynamic cues to support perceptual skill development. | Do realistic cues facilitate perceptual skill development better than concept drawings? | Ability to distinguish healthy from injured: <ul style="list-style-type: none">• Rise and fall of the chest• Breath sounds• Airway |
| 2. Embed attention-directing hints from an AR-generated mentor avatar following incomplete assessment to support cue detection. | Do attention-directing hints from an avatar improve the learner's ability to accurately and efficiently assess a patient's condition? | Ability to: <ul style="list-style-type: none">• Recognize critical cues• Recognize critical cues quickly• Conduct a thorough assessment• Match to expert |
| 3. Embed real-time auditory corrections following erroneous actions to provide immediate feedback. | Do real-time auditory corrections improve learners' ability to accurately and efficiently assess a patient's condition? | Ability to: <ul style="list-style-type: none">• Recognize critical cues• Recognize critical cues quickly• Conduct a thorough assessment• Match to expert |
| 4. Augment the external view of the patient with animations of underlying dynamic anatomy to support mental model development of injury progression, including anticipatory reasoning. | Does exposure to depictions of underlying dynamic anatomy in the context of a challenging scenario improve understanding of injury and ability to predict likely outcomes? | Ability to: <ul style="list-style-type: none">• Accurately diagnose injury• Quickly diagnose injury• Predict likely outcomes with no intervention• Predict likely outcomes with appropriate intervention |

| AR Training Design Principle | Guiding Question | Measures |
|---|--|-----------------------------|
| User Feedback Sessions | | |
| 5. Include time manipulation to support development of mental models of injury progression including anticipatory reasoning. | Do instructors and students anticipate that “fast forwarding” in time to see how an injury progresses without treatment improves understanding of injury and ability to predict likely outcomes? | |
| 6. Support self-reflective learning using an AR-generated mentor that encourages learners to articulate assessments, hypotheses, and rationale to facilitate mental model development. | Do instructors and students anticipate that articulating assessments and hypotheses will aid learners in developing mental models to support assessment skills? | |
| 7. Strategies to encourage reflection and feedback during AR training can improve learning outcomes. | Can the proposed reflection and feedback components including comparison to expert model, replay, ability, and performance scores, be effectively integrated into after-action review? | |
| Summative Study | | |
| 8. AR adaptive training has advantages over existing training. | Is AR adaptive training more effective than existing training? | See Table 2 in next section |

Institutional Review Board (IRB) approval for research activities will be requested from OSU in a two-stage approach, with formative evaluations submitted first to avoid delays if selected for funding. In the second stage, the validation study will be submitted as an amendment once the exact technology and training to be validated has been finalized. The first human subjects research activities are planned for the end of the second quarter of the Phase II project. Dr. Patterson (Co-PI at OSU) turned in the just-in-time IRB submission to the OSU IRB in early April 2018.

Formative Studies

Formative studies will be conducted with medical students at the OSU College of Medicine. Each will include 10 students in an experimental group who receive a key training component, and 10 in a control group who do not.

Study 1: Do realistic cues facilitate perceptual skill development better than concept drawings?

Participants: First and second year medical students.

Materials: For Study 1, we will develop a training module that includes perceptual cues depicting healthy and injured anatomy on virtual patients for the experimental condition. We will build an analogous training module for the control group leveraging descriptions, photos, drawings, and/or animations used in existing training programs. Candidate perceptual skills might include distinguishing:

- Healthy versus atypical breath sounds
- Healthy versus asymmetrical rise and fall of the chest
- Healthy versus jugular vein distention
- Healthy versus atypical skin tone
- Healthy versus swollen airway
- Properly placed versus kinked needle decompression
- Properly placed versus leaky occlusive dressing

We will develop a test to assess learners' ability to make the perceptual distinctions described above.

Procedure: After informed consent, participants will be asked to complete a pre-test assessing their ability to distinguish important perceptual cues. Each participant will work through either the experimental or control training module. After finishing the training module, participants will complete a post-test consisting of the same questions used in the pre-test.

We will compare changes in time and accuracy from pre- to post-test between the experimental and control groups to determine whether the use of realistic cues facilitate perceptual skill development.

Study 2: Do attention-directing hints from an avatar improve the learner's ability to accurately and efficiently assess a patient's condition?

Participants: Second and third year medical students

Materials: For Study 2, we will develop an AR-generated avatar for use by the experimental group. The avatar will appear as the voice of a more experienced medic (or physician) encouraging the learner to notice or look for specific cues. We will develop pre- and post-test scenarios of similar difficulty depicting similar cues and conditions.

Procedure: After informed consent, participants will work through a pre-test scenario. They will be prompted to describe what they are noticing, an assessment of the patient, and recommended interventions. Gaze tracking software will record when they look at specific cues. The experimental group will work through two training scenarios using the AR-generated avatar providing attention-directing hints. The control group will work through the same two training scenarios without attention-directing hints. Both groups will complete the post-test scenario, again articulating what they are noticing, an assessment of the patient, and recommended interventions.

We will compare changes from Time 1 to Time 2 in learners' ability to notice critical cues, quickly and accurately assess the patient, and identify an appropriate course of action. Performance will be scored against an expert model.

Study 3: Do real-time auditory corrections improve learners' ability to accurately and efficiently assess a patient's condition?

Participants: First year medical students

Materials: For Study 3, we will develop an auditory correction that appears when the learner deviates from the ABCDEF assessment algorithm to be used by the experimental group. We will use the pre- and post-test scenarios developed for Study 2.

Procedure: After informed consent, participants will work through a pre-test scenario. They will be prompted to describe what they are noticing as they assess the patient. Gaze tracking software will record when they look at specific cues. The experimental group will work through two training scenarios using the real-time auditory corrections. The control group will work through the same two training scenarios without correction. Both groups will complete the post-test scenario, again articulating what they are noticing as they assess the patient.

We will compare changes from Time 1 to Time 2 in learners' ability to work through the assessment algorithm in the correct order.

Study 4: Does exposure to depictions of underlying dynamic anatomy in the context of a challenging scenario improve understanding of injury and ability to predict likely outcomes?

Participants: First year medical students.

Materials: For Study 4, we will develop animations that show underlying dynamic anatomy in the context of tension pneumothorax and airway obstruction for use by the experimental group. We will use the pre- and post-test scenarios developed for Study 2.

Procedure: After informed consent, participants will work through a pre-test scenario. They will be prompted to describe what they are noticing, an assessment of the patient, and recommended interventions. They will be asked to describe how the patient's condition will progress if untreated, including specific prompts about the underlying dynamic anatomy (i.e., what is happening in the patient's chest cavity). Gaze tracking software will record when they look at specific cues. The experimental group will work through two training scenarios using the dynamic anatomy animations. The control group will work through the same two training scenarios without dynamic anatomy animations. Both groups will complete the post-test scenario, responding to the same probes used in the pre-test.

We will compare changes from Time 1 to Time 2 in learners' ability to notice critical cues, quickly and accurately assess the patient, identify an appropriate course of action, and describe the underlying dynamic anatomy.

User Feedback Sessions

User feedback sessions will be used to obtain feedback about additional design and training components. Sessions will include a combination of medical students, combat medics, and/or instructors. We plan to recruit combat medics from the 256th Combat Hospital U.S. Army Reserve Unit, and from the student population at OSU. We will continue pursuing contacts with combat medic training organizations (i.e., Military Education and Training Command). User feedback sessions may occur at early design stages, working with drawings and design concepts, and later as more detailed prototypes become available. Sessions that take place earlier in the design and development cycle will have smaller samples (i.e., 1-5 participants); those that take place later may have up to 10 participants. In these sessions, participants will be asked to envision using the proposed feature in the context of real-world training. We will explore perceived benefits and drawbacks, feedback about the usability of the proposed design, and anticipated barriers to integration into training. When we have detailed prototypes, participants will interact with the prototype and complete a usability survey (i.e., System Usability Scale, Lewis & Sauro, 2009; Sauro, 2011). We anticipate that topics for user feedback will emerge during the design and development process; however, we have identified three topics for user feedback at this early stage.

Do instructors and students anticipate that "fast forwarding" in time to see how an injury progresses without treatment improves understanding of the injury and ability to predict likely outcomes?

One topic for user feedback sessions is time manipulation. Although the notion is intuitively appealing, time manipulation can be used in several ways. It can be used to extend a scenario, to depict outcomes as part of an after-action review, or as part of a tutorial. User feedback sessions with instructors and learners will help us narrow our focus to identify the most promising use of time manipulation, and to answer the question of whether instructors and students anticipate that this manipulation will improve training.

Do instructors and students anticipate that articulating assessments and hypotheses will aid learners in developing mental models to support assessment skills?

Another topic for which we will obtain user feedback is related to the research literature that suggests that asking learners to articulate assessments, hypotheses, and rationale as they work may support mental model development (Klein & Wolf, 1995; Patterson, Militello, Bungler, Taylor, Klein, & Geis, 2016). Anecdotal advice from combat medic instructors, however, indicates that encouraging this during training may be too much of a deviation from recommended practice (e.g., medics do not announce their thoughts as they work on patients in the real world). User feedback sessions will allow us to explore different strategies for supporting mental model development in this way before we embark on detailed design for a prototype.

Can the proposed reflection and feedback components including comparison to expert model, replay ability, and performance scores be effectively integrated into after-action review?

A third topic is that of encouraging reflection and feedback. The proposed performance summary is

intended to serve this purpose. To be effective it must be compatible with existing after-action review and other feedback strategies. We will obtain user feedback from instructors and learners to better understand existing constraints and how we can leverage AR adaptive training to support both the learner and trainer in reflection and feedback.

Summative Evaluation

Findings from formative studies and user feedback sessions will guide the final design of the MART prototype to be assessed in the summative evaluation. Our primary hypothesis for the summative evaluation is that AR-based adaptive training as instantiated in MART will enable more timely diagnosis and treatment as compared to ‘textbook’ written and verbal descriptions of cues (e.g., ‘increasing respiratory distress’). We will explore the question of whether MART improves perceptual cue recognition, sensemaking, assessment, treatment planning skills, and mental model development. We will assess student reactions and learning of foundational knowledge.

Participants: For the summative evaluation, we will recruit 40 participants. Participants will be OSU medical students. Participants will be reimbursed for participation at \$40/hour.

Materials: We will evaluate a version of the MART system that is specific to emergency department training (*MART-ED*) tailored for use by the OSU College of Medicine. This version will incorporate adaptive training elements deemed most useful based on formative studies and user feedback sessions. In order to reduce asymmetric learning effects associated with using the HoloLens, study participants will use a tablet-based AR training application rather than the HoloLens.

Training and evaluation scenarios will be nearly identical conceptually, with changes limited to demographic variables (e.g., 58 years old instead of 45 years old) and medical conditions which do not directly interact (e.g., other co-occurring injuries to other body parts such as a broken arm vs. a broken leg). In evaluation scenarios, unlike the training scenarios, there will be no requirements to stop treating the patient in order to deal with distracting events in the environment or other patients in order to ensure the integrity of the time measure. The evaluation scenarios will be designed to be Garden Path scenarios.

Design: The study will include a pre-post, between subjects design where half of the participants receive traditional classroom training and half of the participants receive the intervention of the AR training. Participants are randomized to baseline (traditional classroom training) as compared to intervention condition (AR training).

Procedure: After obtaining informed consent, participants will be assigned to their condition and take the pre-test battery. They will receive training (either AR or conventional), then complete the post-test battery, including the Garden Path evaluation scenarios. The Garden Path evaluation scenarios will be video-recorded. Sessions will last 2 hours.

Measures: For this study, we will integrate macrocognitive measures with more traditional instructional system design (ISD) measures. These two perspectives are complementary and overlap in important ways. Table 3 provides an overview of measures to be used in the summative evaluation. Note: ISD constructs are described in terms of those articulated by Kirkpatrick (1998) and Miller (1990) in their discussion regarding what constitutes meaningful evaluation of training interventions.

Table 2. Overview of summative evaluation measures

| Measure | Macrocognition | ISD | Data |
|---|-------------------|-----|------------------------|
| 1. Time to rule out false prime | Sensemaking | | Time |
| 2. Time to full diagnosis | Sensemaking | | Time |
| 3. Proportion of critical cues identified | Perceptual skills | | Think aloud statements |
| 4. Proportion of cues scanned | Assessment skills | | Gaze tracking |
| 5. Order cues are scanned | Assessment skills | | Gaze tracking |

| Measure | Macro cognition | ISD | Data |
|--|--------------------|----------|--------------------------|
| 6. Alternative explanations considered | Sensemaking | | Think aloud statements |
| 7. Action priorities | Treatment planning | | Video record/observation |
| 8. Link dx to treatment priorities | Mental models | | Rationale statements |
| 9. Knowledge of anatomy | Mental models | Learning | Knowledge test |
| 10. Knowledge of treatment priorities | Mental models | Learning | Knowledge test |
| 11. Usability and usefulness | | Reaction | Survey |

During analysis, the collected video data will be compared to an expert model of performance using a theoretical framework of macrocognitive measures. Specifically,

- The times needed to rule out the false prime explanation (Measure 1) and to come to an accurate diagnosis (Measure 2) will be compared with expectations for experts;
- The cues identified as critical by participants (Measure 3) will be compared to critical cues identified by experts;
- The proportion of possible cues to detect (Measure 4) and the order in which they are scanned (Measure 5) to aid in diagnosis/sensemaking will be compared to the full possible set that experts would detect based upon gaze tracking data;
- Think-aloud statements (Measure 6) will provide evidence that participants considered alternative explanations (differential diagnosis) or the possibility of masked conditions (interacting diagnoses), which is a marker of high expertise in sensemaking;
- Actions taken to ‘safe’ a patient such as stabilizing blood pressure or ensuring an intact airway (Measure 7) will be used as evidence for expert management of the trade-offs between diagnosis and stabilization of the patient; and
- The clarity of justifications for inferences relating to diagnosis and how to prioritize treatment actions (Measure 8) will be assessed by emergency medicine SMEs in relation to level of sophistication and clarity.

It is important to note that these are scenario-specific measures. For example, a directly observable performance measure for the tension pneumothorax scenario is the primary measure of time until full diagnosis of a blast injury resulting in a tension pneumothorax. The Garden Path scenario will point to a different diagnosis; in this way, there will be an objective ‘start’ time for measurement until the participant has reached an accurate diagnosis. For the airway obstruction scenario, the primary measure is time until diagnosis of a burn injury as a result of breathing superheated air, resulting in airway obstruction.

In addition to macrocognitive measures, we will implement measures recommended by Kirkpatrick (1998) and Miller (1990). When applying this evaluation framework, the focus will include survey responses regarding attitudes about the training itself (Level 1 evaluation), test scores assessing knowledge (Level 2 evaluation), and directly observable performance measures (Level 3 evaluation). These ISD-based components establish a critical baseline for evaluation. Specifically, the participants will complete:

- A knowledge test regarding relevant anatomy (Measure 9),
- A knowledge test regarding which treatment activities to prioritize with respect to the scenario-specific elements (e.g., ensure there is no internal bleeding before assessing the extent of burn injuries on skin; Measure 10), and
- A usability and usefulness survey (Measure 11). The usefulness survey will aid in assessing whether participants judge that the virtual patient reacts as a human would in the real world,

whether they find the training experience valuable, and will include comparison to alternative platforms such as online training delivery.

Conclusions. This series of evaluations will test the effectiveness of MART, along with articulating how the system's components affect training. Results from the formative evaluations will be integrated into the software development, in line with user-centered design principles. We will use medical school students and resident physicians for most of the studies because they are more accessible than combat medics. However, we will incorporate combat medic feedback through their involvement in the formative user-feedback sessions.

The use of augmented and virtual reality medical training has proliferated in recent years. Although these efforts are often met with enthusiasm, limited research has been conducted to identify effective strategies for designing and implementing AR-based medical training, resulting in a broad range of applications with little understanding of strengths and weaknesses of different approaches and techniques (Barsom, Graafland, & Schijven, 2016; Zhu, Hadadgar, Masiello, & Zary, 2014). Research-based design principles are needed to articulate best practices in AR-based training design. The outcome of this series of studies will be a better understanding of how specific AR and adaptive training elements affect training outcomes in the medical domain.

3. KEY RESEARCH ACCOMPLISHMENTS

The key research accomplishments of this Phase I project include:

1. Successful demonstrations of novel solutions to virtual patient registration to a physical manikin.
2. Created challenging, realistic training scenarios with associated expert models.
3. Adapted the garden path scenario method for use in emergency medicine domain.
4. Built virtual patient assets that could be incorporated into existing AR software platforms.
5. Identified adaptive training components that AR affords during the completion of realistic scenarios.
6. Developed a strategy for evaluating the effectiveness of individual training components that will lead to theoretically-based principles for designing AR adaptive training.

4. CONCLUSION

Augmented reality has the potential to improve on the already successful TCCC training. The ability to present realistic visual and auditory cues allows the learner to practice perceptual skills in a simulated environment as never before. By integrating the AR virtual patient with a physical manikin and embedding the training in compelling realistic scenarios, we can create a holistic training experience that exercises perceptual skills, assessment, sensemaking, and the application of medical procedures in a unified training experience. Furthermore, AR opens the door for including a range of adaptive training features in the simulated training experience. The promise of a sea change in combat medic training is inviting; however, it is important to document lessons learned throughout the design process, and to assess the effectiveness of individual components of AR-based adaptive training. The goals of this research program are two-fold: 1) to improve combat medic training and 2) to develop a set of evidence-based principles to guide the design of AR training.

This Phase I project moves us closer to these goals. We established the technical, commercial, and scientific feasibility of our approach to AR-based adaptive training.

Technical Feasibility

In terms of technical feasibility, the Phase I research efforts related to Objective 1 (overcome technological barriers in mapping AR content to physical manikin) and Objective 2 (develop AR training

prototype), established the merits of our approach. Early feedback from military clients indicated that it was vital that the virtual patient and physical manikin move in sync for effective scenario-based training. We identified and tested several technological solutions to this requirement. We were able to demonstrate that the technologies could be incorporated into MART. During the Phase I, we also designed AR assets and adaptive training components that can be built into MART during the Phase II. Certain elements were already incorporated into the prototype - specifically the virtual patient assets associated with each of our training scenarios. Other elements (e.g., adaptive training components) have been articulated and vetted against the existing state of the technology. We are confident that we can build them into MART.

Commercial Feasibility

In terms of commercial feasibility, during the Phase I effort we made connections to both military and civilian commercial outlets. We have an existing partnership with Innovative Tactical Training Solutions (ITTS) that has contracts with military clients. ITTS has a marketing and sales team already in place that have been trained to market one of our existing products, the Virtual Patient Immersive Trainer (VPIT). ITTS plans to continue supporting our marketing efforts during the Phase II. Our university partner, Ohio State University, has also expressed interest in purchasing a version of MART for use in their residency training program. OSU has a state of the art simulation facility, and is interested in growing their capabilities to include emerging technologies. Outside of our team, the director of the simulation center at Cincinnati Children's Hospital Medical Center (CCHMC) has expressed a strong desire and need for AR technology in the CCHMC simulation center.

Working with the OSU College of Medicine, we have also begun to explore how MART can be integrated into the existing curricula. OSU is a leader in medical education. Use of MART for airway management and tension pneumothorax training will position OSU to serve as a 'best practice' model for implementation of AR-based training to other academic medical centers, sharing lessons learned via traditional dissemination pathways. We have three physicians on our team for the Phase II who will assist in creating the practice model, including Dr. Susan Moffatt-Bruce, executive director of University Hospital, who will serve as the interested customer for purchasing the technology and associated training. OSU represents an influential partner that will strengthen our commercialization efforts.

Scientific Feasibility

Based on our review of the relevant literatures and the expertise of our team members, we have begun to theorize about the elements of AR training that will be most effective. The components and structure of MART's adaptive training that we articulated in the previous sections reflect our theoretical framework. We have articulated a detailed plan for assessing the strengths and limitations of individual adaptive training components leveraging the AR technology in MART training. In the Phase II, we plan to test key components of our training system to identify research- and theory-based design principles that can be applied to other AR training applications, resulting in a *Guide to Designing Effective AR Adaptive Training*.

Summary

During this Phase I effort, we successfully advanced the state of AR training by developing innovative strategies for aligning a virtual patient with a physical manikin. We established important partnerships with ITTS manikin manufacturer and The Ohio State University College of Medicine to promote commercialization in both military and civilian health sectors. We articulated a plan for evaluating the impact of AR on learning to lead to scientifically-founded principles for designing AR-based training. We are well-positioned to implement technological advances identified during Phase I research, conduct formative and summative evaluations as part of the development cycle, and continue down the path to commercialization in a Phase II project.

5. PUBLICATIONS, ABSTRACTS, AND PRESENTATIONS

We presented a poster (Appendix B) and gave a demonstration at the 2018 Human Factors and

Ergonomics Society Healthcare Symposium, held in Boston, MA March 26-28, 2018. Final manuscripts are due by April 23, 2018 for inclusion in the conference proceedings. The funding of this project is acknowledged in all publications. We will send the finalized manuscripts to the sponsor and COR when we submit.

Militello, L., Sushereba, C., Fernandez, S., & Patterson, E. (2018, March, *in press*). *A systematic method for using critical decision method interviews to generate a garden path scenario for human-in-the-loop simulations for training and evaluation of new technologies*. Poster session presented at the Human Factors and Ergonomics Society Healthcare Symposium, Boston, MA.

Militello, L. & Sushereba, C. (2018, March, *in press*). *Augmented reality for recognition skills training*. Demonstration presented at the Human Factors and Ergonomics Society Healthcare Symposium, Boston, MA.

6. INVENTIONS, PATENTS, AND LICENSES

A number of the software prototype elements developed during the project build on patent filings that pre-date the Phase I project (Application Serial No. 62/483,171). No new patent filings were made during the project period. However, progress on the adaptive training schema, and each of the registration prototypes (i.e., skeleton tracking, marker-based tracking, and IMUs) will be added to our prior filings. An updated filing is expected on or before April 6th, 2018.

7. REPORTABLE OUTCOMES

Progress made during the Phase I has supported improvements to our commercial software development efforts. The VPIT 1.0 software launched during the course of the project (see Press Release in Appendix C).

8. OTHER ACHIEVEMENTS

Nothing to report.

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10. APPENDICES

Appendix A: Training Scenarios with Expert Models Available Kit

Combat Medic

- CAT tourniquet (2)
- ETD (2 - 6 in.)
- ETD abdomen
- S-rolled gauze (4)
- Combat gauze (2)
- Tactical comp wrap
- Naso (2 airway and lube)
- King LTS-D
- Cyclone BVM packet
- Tactical suction
- Tactical CrikKit
- HyFin (vent, twin pack)
- ARS needle, 14g (2)
- BOA standard
- Saline lock kit (4)
- Sharps shuttle
- Splint tactical traction
- SAM splint (2)
- Trauma shears (large)
- 7 hook safety cutter
- 2 in. Tape (2)
- Case Armadillo
- Nitrile gloves (8 pairs)
- PES eye shield
- Combat casualty card (4)
- Casualty reference card
- Permanent marker



Figure 12. NAR-4 Aid Kit from North American Rescue website:
<https://www.narescue.com/pre-hospital-care-ems-products/casualty-response-kits/nar-4-aid-kit>

Tension Pneumothorax

Context: An explosive ordnance disposal (EOD) soldier was attempting to neutralize a small improvised explosive device (IED). The IED detonated during the deactivation attempt, causing a blast lung injury, temporary loss of consciousness, blunt force trauma to the rib cage, and burns to the patient's hands. The patient was thrown approximately 2 meters away from the blast site, and landed on pavement.

This is an active combat situation, so key concern is security. Patient is a male, 20-23 years old, approximately 180 lbs.

Time 1: 30-60 seconds after POI

Right after the point of injury (POI), you are able to do a quick assessment of the patient, but you must stay alert to the combat conditions. You see the following:

- There is no massive hemorrhage visible
- There is some blood in the patient's mouth
- The patient has close to full respirations. The inhalation volume is decreased, rate of breathing is fast, and the patient is having difficulty breathing.
- Patient is expressing pain.
- Patient asks, "What happened?"
- There are superficial and partial thickness burns to the patient's hands.
- The patient's bomb suit is damaged, smoldering, and stitching is torn on his clothes.

Your assessment is interrupted by active fire, so you must shift focus to site security.

Expert Model

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| Important cues: |
| 1. Difficulty breathing |
| 2. Increased rate of breathing |
| 3. Decreased volume of breathing |
| 4. Mental status |
| 5. Patient is talking, so airway is patent |
| 6. Lack of massive hemorrhage |
| Differential diagnosis: |
| 1. Pneumothorax – either regular or hemothorax |
| 2. Pulmonary contusion |
| 3. Possible airway injury (inhalation burns) |
| 4. Possible head injury |
| Planned actions: |
| 1. Secure the environment and the patient |
| 2. Position the patient for airway management |
| 3. Expose the patient and do a body sweep |
| 4. Check trunk for any lacerations and apply occlusive dressing |
| Anticipated patient progression: |
| 1. Patient will deteriorate. |
| Triage level: |
| Urgent – Cat A |

Time 2: 15 minutes after POI

Your team has secured the area, and you are able to continue your assessment of the patient. You observe the following:

- There is no external bleeding
- Blood in the mouth, and now you notice some broken teeth (not obstructing the airway). It looks like the patient bit his cheek and tongue.
- You remove his shirt and see bruising on his right rib cage, near the nipple line. There is a slight paradoxical motion to his right lateral chest wall. The patient has increased difficulty and effort of breathing.
- Patient is talking in short sentences and alert.
- The patient's voice is hoarse and he's coughing.
- There are superficial and partial thickness burns to the hands and face.

You are now able to move the patient to a more secured area where you can administer more advanced treatments.

Expert Model

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|---|
| Important cues: |
| 1. Bruises on the rib cage |
| 2. Paradoxical chest wall motion |
| 3. Flail chest segment |
| 4. Difficulty breathing |
| 5. Patient talking in short sentences |
| Differential diagnosis: |
| 1. Pneumothorax – either hemothorax or tension pneumothorax |
| 2. Flail chest |
| 3. Pulmonary contusion |
| Planned actions: |
| 1. Assess and clear the oral airway |
| 2. Needle decompression |
| 3. Dress wounds, burp any chest seals |
| 4. Pain management |
| Anticipated patient progression: |
| 1. The patient will decompensate rapidly, leading to death. |
| Triage level: |
| Urgent – Cat A |

Time 3: 45-60 minutes after POI

The patient is now in a secure and protected area. You re-assess after moving the patient, and observe the following:

- No external bleeding
- The patient is breathing rapidly and wheezing. He is becoming hypoxic and cyanotic.
- The paradoxical motion in the rise and fall of his chest is more pronounced, and now you see a flail chest segment. The bruises on his torso are larger and have changed color. You see unilateral rise and fall of his chest.
- The patient is confused and his skin is paler.
- Some of the blisters in the burned area to the hands and face ruptured while the patient was being moved to the new location.

Expert Model

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| Important cues: |
| 1. Cyanosis |
| 2. Shock, pale skin |
| 3. Hypoxia |
| Differential diagnosis: |
| 1. Pneumothorax – tension pneumothorax, possibly hemothorax |
| Planned actions: |
| 1. Needle decompression |
| 2. Listen to the lungs |
| 3. Airway management (supraglottic) |
| 4. Place chest tube |
| 5. Give blood, fluid, or TXA |
| 6. Oxygen |
| Anticipated patient progression: |
| 1. The patient will rapidly decline and die. |
| Triage level: |
| Urgent – Cat A |

Time 4: 3 hours after POI

The patient still has not reached a definitive care facility, but he is sheltered in a secure location. You reassess him and notice the following:

- No external bleeding
- Patient is excessively coughing with productive red sputum, has decreased breath sounds, and there is blood coming out of his mouth.
- You see unilateral rise and fall of the chest, and the bruises on his torso have worsened.
- He shows jugular vein distention and tracheal deviation.
- His skin is pale, and he is in and out of consciousness. His pupils are sluggish to respond to light when his eyes are open.

Expert Model

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|--------------------------------------|
| Important cues: |
| 1. Jugular vein distention |
| 2. Tracheal deviation |
| Differential diagnosis: |
| 1. Tension pneumothorax |
| Planned actions: |
| 1. Needle decompression |
| 2. Continue with treatment protocols |
| 3. Assess mentation |
| 4. Listen to breathing |
| Anticipated patient progression: |
| 1. Patient will die. |
| Triage level: |
| Urgent – Cat A |

Airway Obstruction

Context: An RPG strikes the driver side front door of an up-armored vehicle in a convoy. The driver (wearing a ballistic helmet, body armor, and gloves) was closest to the explosion and remained entrapped in the vehicle for approximately 90 seconds before his teammates are able to pull him from the burning wreckage. He receives partial and full thickness burns around his neck, jaw, and upper cheeks. The body armor protected his chest from any direct burns or penetrating injury. The soldier's upper extremities were hit with shrapnel and debris. His gloves protected his hands, but there are ring burns around his wrist.

Time 1: Immediately following POI

You are traveling with the security convoy and are able to get to the patient shortly after he was removed from the burning vehicle. After moving the patient to a secure location, you make the following observations during your initial assessment of the patient:

- There is no massive hemorrhaging noted.
- There is blood on his uniform from lacerations to his arms, but none of the injuries have created arterial bleeding.
- The patient has singed nostril hairs and reddening of the skin on his face. There are also small pieces of shrapnel in his face. His lips are red, like they've been sunburned. There are no major secretions in his mouth and his neck looks normal.
- His voice is hoarse and he's coughing. He has increased respirations. There is bilateral rise and fall of his chest, and normal expansion and contraction of his rib cage.
- Patient is conscious and in pain. He is speaking in coherent words, but he is rambling and does not appear to be fully aware of what happened. He looks dazed and stressed.
- Carotid and radial pulses are the same.
- The patient's skin feels warm/hot to the touch.
- He is sweaty, and has light burns in addition to the lacerations on his arms.

Expert Model

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| Important cues: |
| 1. Patient's voice is hoarse |
| 2. Singed nostril hairs |
| 3. Skin on patient's face is red and burned |
| 4. Respirations are fast |
| Differential diagnosis: |
| 1. Thermal injury to the airway |
| 2. Possible TBI |
| Planned actions: |
| 1. Maintain security |
| 2. Position patient to manage the airway |
| 3. Assess the patient's mouth for swelling, carbonaceous sputum, and other secretions; suction and clear the mouth |
| 4. Expose the patient and do a full body sweep for other injuries |
| Anticipated patient progression: |
| 1. Patient is sick – his airway is significantly compromised, which will lead to respiratory distress and death if not managed. |
| Triage level: |
| Urgent – Cat A |

Time 2: 5-10 minutes after POI

The patient is lethargic and in obvious respiratory distress, so you reassess his condition. You notice the following on your reassessment:

- No additional bleeding.
- Tissue along the airway is beginning to swell, and the patient is coughing up thick carbonaceous sputum with some yellow-green phlegm and blood. The cough is productive.
- There is some bleeding inside the mouth from the patient biting his cheek.
- The redness on the skin around the patient's mouth is darkening. Blisters are forming across the patient's cheeks and forehead.
- The nostrils are becoming smaller.
- There is general swelling around the patient's face – his lips and tongue are becoming larger.
- There seem to be more secretions in his mouth (from swelling and inability to swallow), and the oral pharynx is starting to close up, becoming more voluminous and wet. The secretions are light to dark gray with black specks.
- The patient's pulse ox is 86%.

Expert Model

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| Important cues: |
| 1. Patient is coughing up carbonaceous sputum |
| 2. Airway is swelling |
| 3. Nostrils are smaller and the face is swelling |
| Differential diagnosis: |
| 1. Airway obstruction due to thermal burns and edema |
| Planned actions: |
| 1. Advanced airway – cric or intubate |
| 2. Oxygen/ventilate |
| Anticipated patient progression: |
| 1. Airway obstruction will lead to death |
| Triage level: |
| Urgent – Cat A |

Time 3: 15 minutes after POI

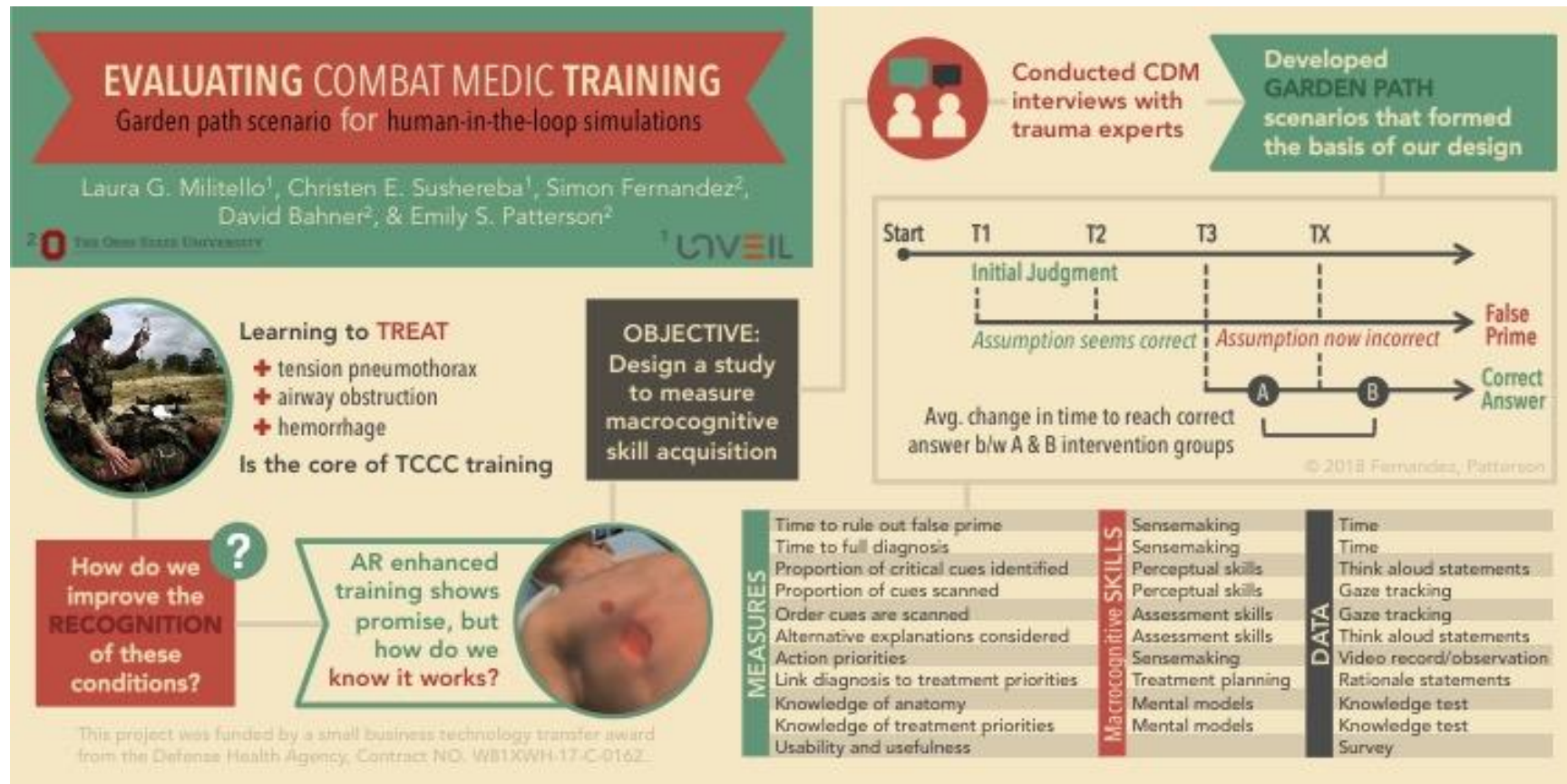
Non-surgical attempts at managing the patient's airway have failed. The patient is worsening, and you observe the following:

- Tissue in the nose and mouth is significantly swollen. The patient's lips are triple in size.
- Larger blisters are forming on the patient's face.
- Carbonaceous sputum and secretions are very prominent.
- You hear stridor.
- The patient is wheezing, and you hear wet lung sounds. There is an increased effort of breathing and an increased rate of breathing. There is decreased tidal volume.
- The patient is fatigued.
- The patient's pulse ox is 76%.
- The patient has a muted cough.

Expert Model

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| Important cues: |
| 1. Stridor/wheezing |
| 2. Airway swelling is worse |
| 3. Hypoxia |
| Differential diagnosis: |
| 1. Impending respiratory failure from airway obstruction due to thermal burns and trauma |
| Planned actions: |
| 1. Cric or other type of surgical airway |
| 2. Oxygen/ventilation |
| Anticipated patient progression: |
| 1. Respiratory failure and death |
| Triage level: |
| Urgent – Cat A |

Appendix B: Poster Submission to HFES Healthcare Symposium



Appendix C: VPIT 1.0 Press Release

FOR IMMEDIATE RELEASE:

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Unveil Announces Release 1.0 of Virtual Patient Immersive Trainer

Cincinnati, Ohio, March 15th, 2018 – Unveil, a healthcare training technology company in Cincinnati, Ohio has announced the first release of their augmented reality-based training software designed for emergency combat medicine. The Virtual Patient Immersive Trainer, or VPIT, enhances the realism of emergency medical conditions such as tension pneumothorax, massive hemorrhage, and airway obstruction.

The VPIT works in conjunction with a physical training manikin to support the development of both recognition and treatment skills. The software is a companion to the Innovative Tactical Training Solutions' industry-leading TOMManikin. The VPIT software includes scenario-based instruction for combat medicine students, as well as coaching and audit tools for instructors. Wearing a mixed reality headset, students see a realistic virtual patient whose appearance adaptively changes based on the treatment path chosen by the student or trainee. Students make real physical interventions on the TOMManikin which result in changes to both the physical and the virtual patient. Instructors control the flow of the scenario and receive reports that summarize student performance to improve after action review sessions.

The entire VPIT 1.0 augmented reality experience is delivered through the Microsoft HoloLens. The software comes pre-loaded on the HoloLens hardware and includes the Tactical Combat Casualty Care (TCCC) module.

“We are extremely excited to release VPIT 1.0,” said Unveil Co-Founder and CEO Steve Wolf. “We think that our integration with the TOMManikin is truly unique. It builds on the value of ITTS’s existing simulation manikin by bringing cutting-edge realism to the diagnostic, triage, and treatment training experience.”

“Now instructors can use these AR-enhanced manikins to train students not only on how to perform medical interventions, but also how to recognize the subtle physical signs and symptoms of dangerous conditions,” said Unveil Co-Founder and Combat Rescue Officer, Oliver Smith.

The VPIT is available for purchase through the ITTS website. For additional information please visit www.tommanikin.com

About Unveil, LLC

Unveil is a training technology company located in Cincinnati, Ohio. Unveil was founded in 2016 and provides augmented reality-based training systems for emergency medical providers in the commercial and military industries.

For more information, contact Christen Sushereba – christen@unveilsystems.com

Appendix D: List of Paid Personnel

The following personnel were paid on this project:

Unveil, LLC:

- Laura Militello, Principal Investigator
- Christen Sushereba, Research Associate
- John Hendricks, Creative Technologist
- Oliver Smith, PJ, Subject Matter Expert
- Julie DiIulio, Visual Designer
- Jason Van Cleave, Software Programmer
- *Steve Wolf, Commercialization Lead (unpaid in kind effort)*

Ohio State University:

- Emily Patterson, Co-Principal Investigator
- David Bahner, MD, Subject Matter Expert
- Simon Fernandez, Research Assistant
- Jacob Socha, Research Assistant

Stottler Henke Associates, Inc.:

- Sowmya Ramachandran, Adaptive Training Consultant

Innovative Tactical Training Solutions:

- Keary Miller, Commercialization Partner